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THE EFFECT OF TEMPERATURE UPON THE GROWTH OF LABORATORY-HELD POSTLARVAL PENAEUS AZTECUS

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THE EFFECT OF TEMPERATURE UPON THE GROWTH OF LABORATORY-HELD POSTLARVAL PENAEUS AZTECUS [1]

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The general life-history of North American shrimp of the genus *Penaeus* has been known for some time (Weymouth, Lindner and Anderson, 1933; Pearson, 1939; Burkenroad, 1934). Adults of the white shrimp, *P. setiferus,* the most intensely studied species, spawn offshore. The young move to the estuaries and, after a period of rapid growth, return to the offshore spawning grounds. During the estuarine phase of the life cycle, the postlarvae, and later the juveniles, are exposed to wide variations of temperature and salinity. Although it has been suggested that the lower salinities of the estuaries are necessary to the growth and survival of these postlarval penaeids (Pearse and Gunter, 1957; Gunter, Christmas and Killebrew, 1964), recent laboratory studies indicate that salinity *per se* has little effect on growth of postlarval *P. aztecus* (Zein-Eldin, 1963).

Zein-Eldin and Aldrich (1965) suggested that temperature was of greater significance than salinity for growth and survival of *P. aztecus.* Their experiments were, however, conducted at only four temperatures: 11°, 18°, 25°, and 32° C. The resulting data indicated greater differences in growth rate between groups held one month at 11° and 18° C. or those at 18° and 25° C., than between groups held at 25° and 32° C. The greatest growth-differential per 7 degrees was between 18° and 25° C.

As a result of these experiments, we decided to make a more exhaustive study of the effects of temperature in the range (15°–35° C.) commonly encountered by the postlarvae.

METHODS

Postlarval *P. aztecus* were obtained from the surf zone of the Gulf of Mexico at the entrance to Galveston Bay and kept in the laboratory for 24 hours before introduction into experimental aquaria. Postlarvae were tested at five constant temperatures in each of two series. In Series 1, we tested at temperatures of 15° through 25° C. at intervals of 2.5°, and in Series 2, temperatures of 25° through 35° C. at the same intervals. Animals were obtained for Series 1 in April, 1964, from water of about 23° C., and for Series 2 in August, 1964, from water of about 29° C.

Groups of 20 postlarvae were placed in glass aquaria containing 4 liters of continuously aerated and filtered bay water (salinity approximately 25‰). Five such aquaria, prepared as described by Zein-Eldin (1963), containing a total of 100 animals, were held in darkness at each constant temperature in B.O.D.-type

[1] Contribution No. 216, Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

TABLE I

Mean animal weight (mg.) and length (mm.) at each temperature level (°C.)
Values are based on samples of 10, except where indicated. Figures in parentheses indicate one standard error

Temperature	Series 1									
	15°		17.5°		20°		22.5°		25°	
Elapsed time (days)	Mean length (mm.)	Mean weight (mg.)	Mean length (mm.)	Mean weight (mg.)	Mean length (mm.)	Mean weight (mg.)	Mean length (mm.)	Mean weight (mg.)	Mean length (mm.)	Mean weight (mg.)
0	12.0 (0.3)	5.1 (0.2)	12.0 (0.2)	5.1 (0.2)	12.0 (0.2)	5.1 (0.2)	12.0 (0.2)	5.1 (0.2)	12.0 (0.2)	5.1 (0.2)
5	12.2 (0.3)	5.2 (0.4)	12.0 (0.2)	7.0 (0.4)	12.4 (0.3)	8.2 (0.3)	12.6 (0.3)	9.0 (0.7)	13.5 (0.3)	12.2 (0.7)
10	12.7 (0.2)	7.4 (0.5)	12.4 (0.3)	8.7 (0.7)	12.8 (0.4)	10.5 (1.2)	13.5 (0.3)	14.7 (1.2)	14.6 (0.8)	29.1 (4.1)
14	11.8 (0.3)	7.0 (0.8)	12.6 (0.3)	9.6 (0.7)	13.9 (0.5)	15.2 (1.4)	16.7 (0.6)	30.0 (1.2)	18.4 (1.0)	49.9 (9.6)
20	12.0 (0.2)	7.4 (0.4)	13.2 (0.5)	12.8 (1.5)	16.6 (0.6)	28.2 (3.0)	18.9 (0.6)	43.8 (3.8)	22.6 (2.0)	90.2 (18.3)
25	12.2 (0.2)	7.9 (0.5)	14.4 (0.2)	15.2 (0.8)	19.1 (0.9)	43.3 (6.1)	21.2 (0.8)	64.7 (7.5)	28.5 (0.9)	158.7 (13.6)
31 Sample of 10	12.7 (0.3)	9.6 (0.8)	15.0 (0.3)	17.6 (1.4)	20.8 (0.6)	50.9 (4.4)	24.3 (1.2)	97.2 (7.0)	34.0 (1.3)	264.3 (33.2)
All survivors	12.6 (0.2)	9.8 (0.5)	14.5 (0.2)	16.7 (0.8)	20.7 (0.3)	52.2 (2.9)	23.9 (0.6)	90.6 (2.9)	33.0 (0.8)	241.7 (18.4)
No. of survivors	30		37		44		41		29	
No. of artificial deaths	2		2		5		7		19	
No. removed for sampling	52		50		50		51		49	

	Series 2									
	25°		27.5°		30°		32.5°		35°	
0	9.4 (0.1)	3.6 (0.2)	9.4 (0.1)	3.6 (0.2)	9.4 (0.1)	3.6 (0.2)	9.4 (0.1)	3.6 (0.2)	9.4 (0.1)	3.6 (0.2)
5	10.4 (0.2)	5.4 (0.6)	10.9 (0.3)	6.7 (0.6)	11.6 (0.3)	8.7 (1.0)	11.4 (0.4)	8.5 (1.0)	10.6 (0.2)	7.0 (0.7)
11	13.4 (0.4)	16.3 (1.2)	15.9 (0.6)	29.1 (2.8)	17.0 (0.5)	35.5 (3.3)	16.4 (0.7)	33.4 (4.0)	10.9 (0.2)	7.4 (0.5)
15	16.0 (0.3)	33.0 (2.2)	20.5 (0.7)	57.5 (6.0)	21.5 (1.0)	72.2 (8.8)	19.6 (0.9)	55.5 (6.6)	11.2 (0.4)	8.7 (1.1)
20	21.0 (1.3)	65.5 (8.9)	21.8 (1.6)	76.8 (15.2)	25.0 (1.2)	108.4 (14.2)	25.3 (1.0)	113.6 (13.9)	—	—
25	24.7 (0.9)	101.9 (12.2)	25.1 (1.7)	124.6 (18.5)	31.0 (1.7)	224.6 (35.8)	29.0 (1.7)*	199.4 (36.7)	—	—
29 Sample of 10	27.2 (1.0)	140.4 (13.6)	31.2 (1.9)	230.7 (32.7)	32.2 (2.6)	272.9 (46.0)	34.0 (1.7)	299.6 (47.5)	—	—
All survivors	26.4 (0.4)	125.6 (6.2)	30.5 (1.2)	219.8 (20.4)	32.3 (1.8)	265.8 (32.1)	34.0 (1.7)	299.6 (47.5)	—	—
No. of survivors	37		30		15		10		0	
No. of artificial deaths	5		7		14		19		30	
No. removed for sampling	50		50		50		45		20	

* Sample of 5.

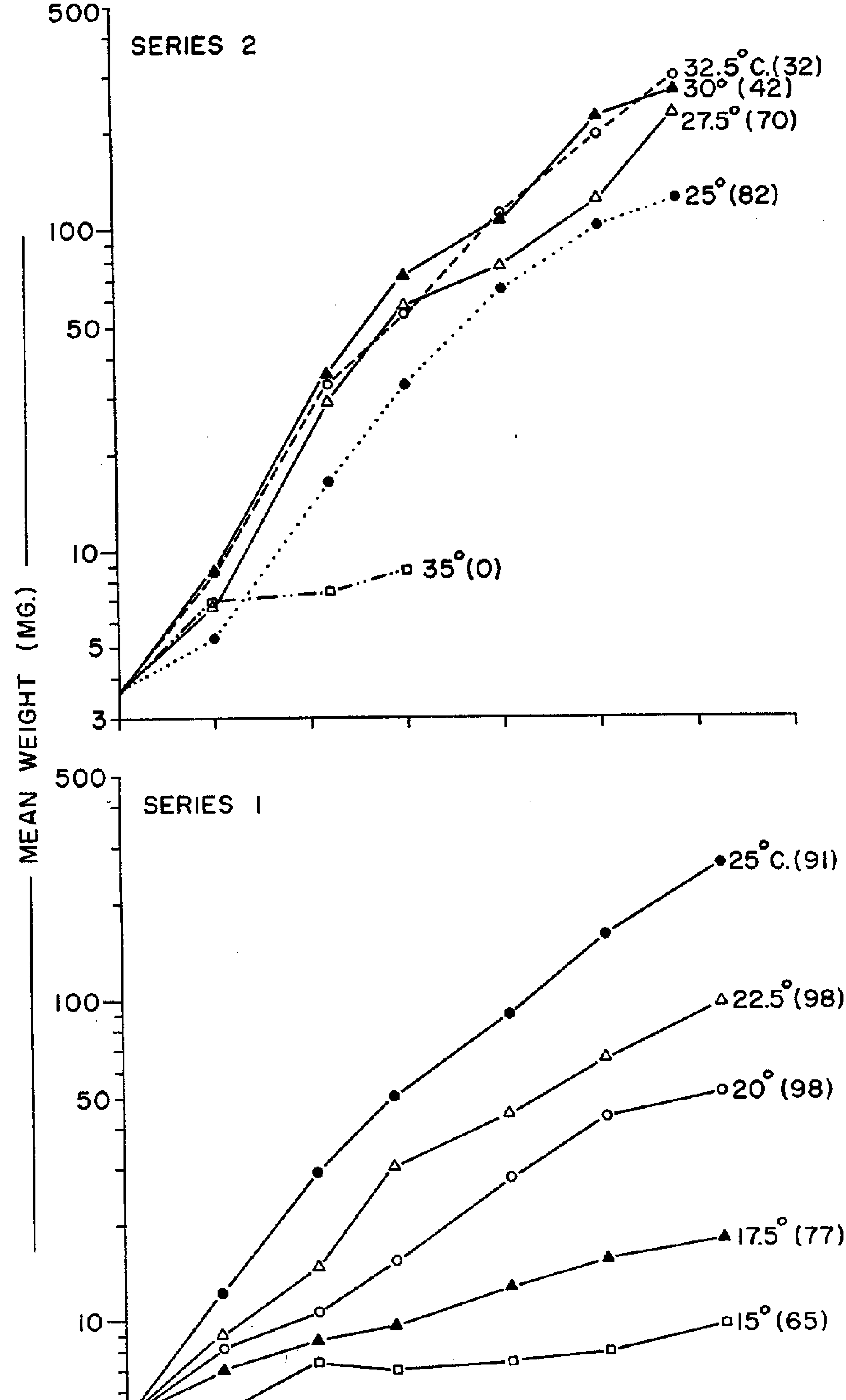

FIGURE 1. Mean increase in weight of *P. aztecus* postlarvae exposed to different temperatures (°C.) for one month. Figures in parentheses indicate per cent survival.

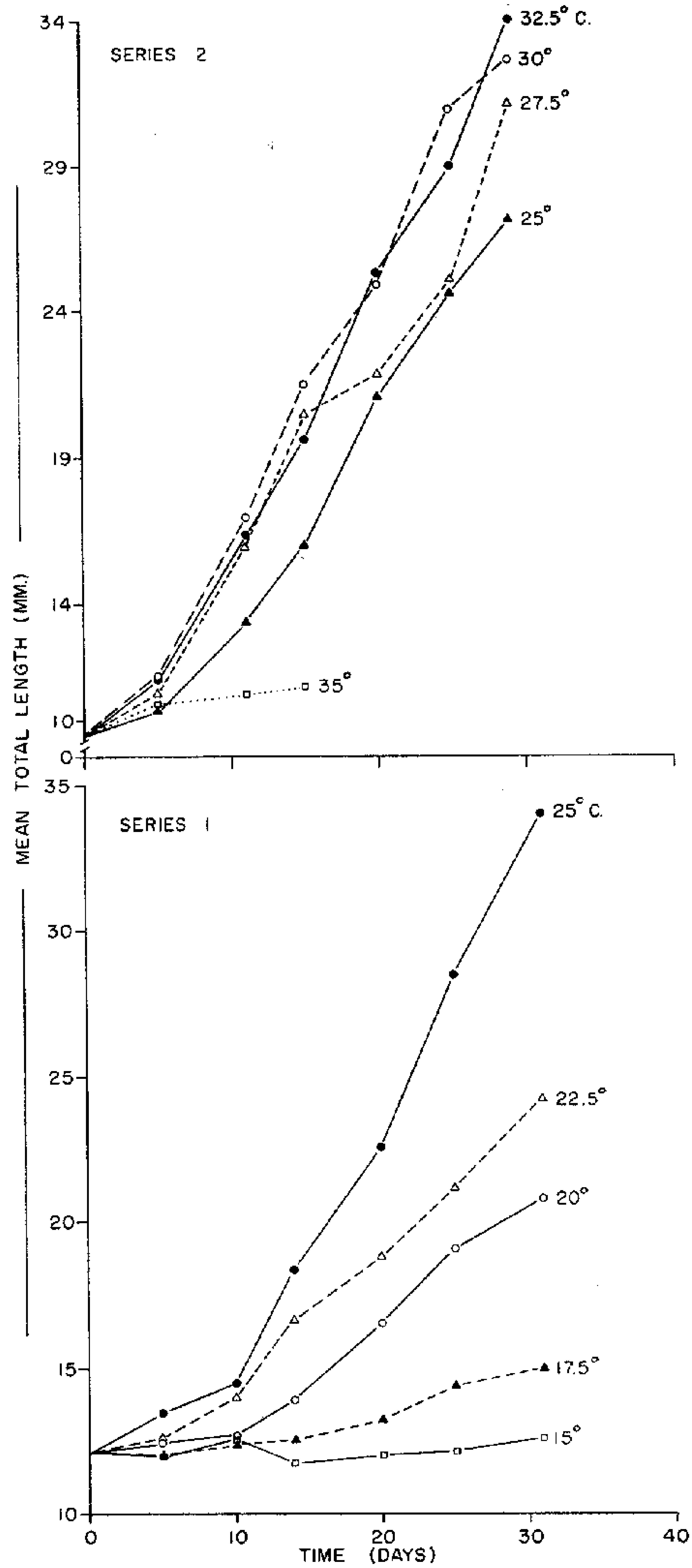

FIGURE 2. Mean increase in length of *P. aztecus* postlarvae exposed to different temperatures for one month.

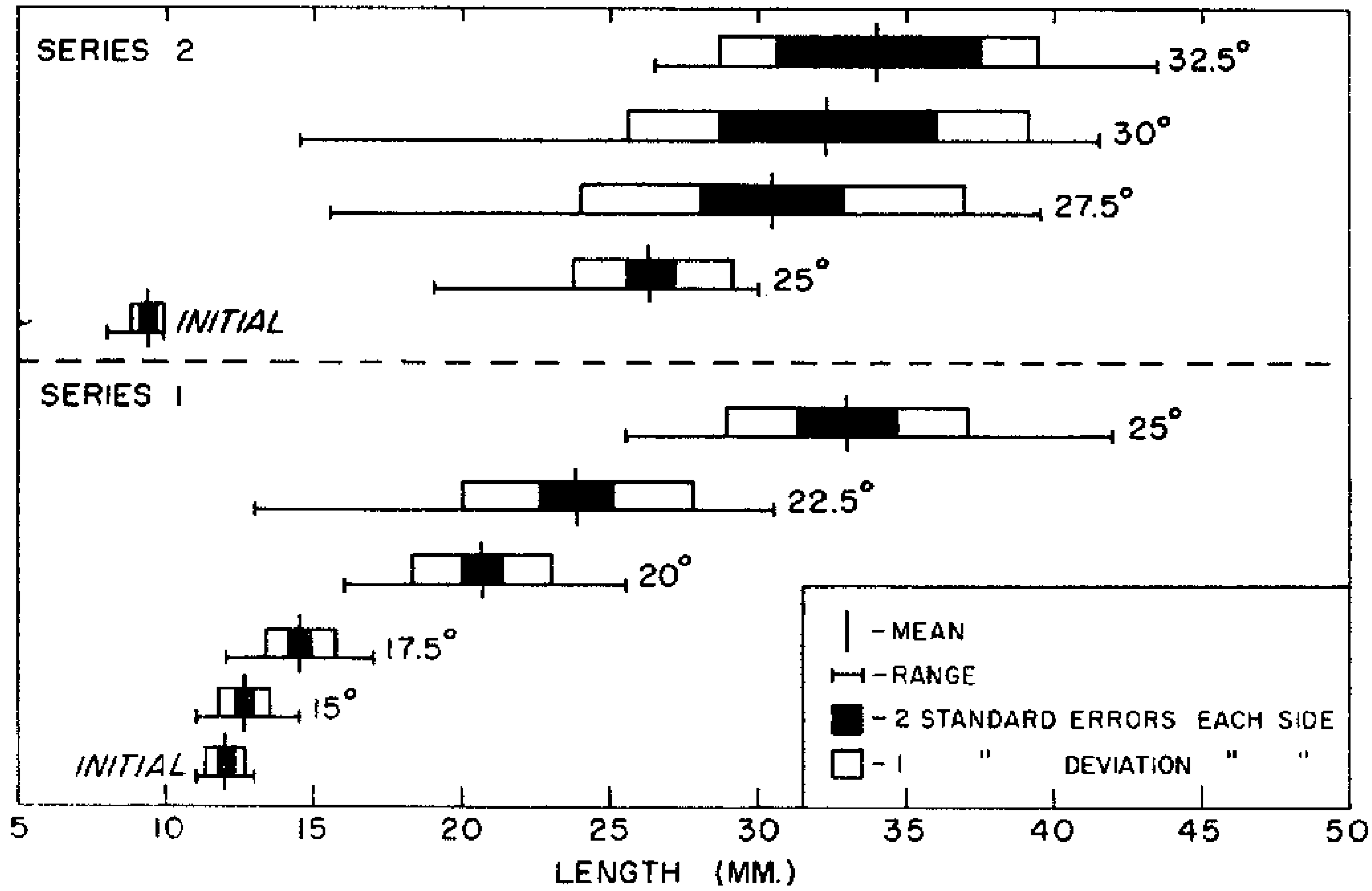

FIGURE 3. Length range (mm.) of postlarval *P. aztecus* surviving exposure to various temperatures for one month.

incubators. The incubators were adjusted over a period of 36 hours from room temperature (approximately 23° C.) to the final experimental temperature.

Experimental animals were fed sufficient live nauplii of brine shrimp (*Artemia*) to keep food constantly available during the month of the study. At each sampling

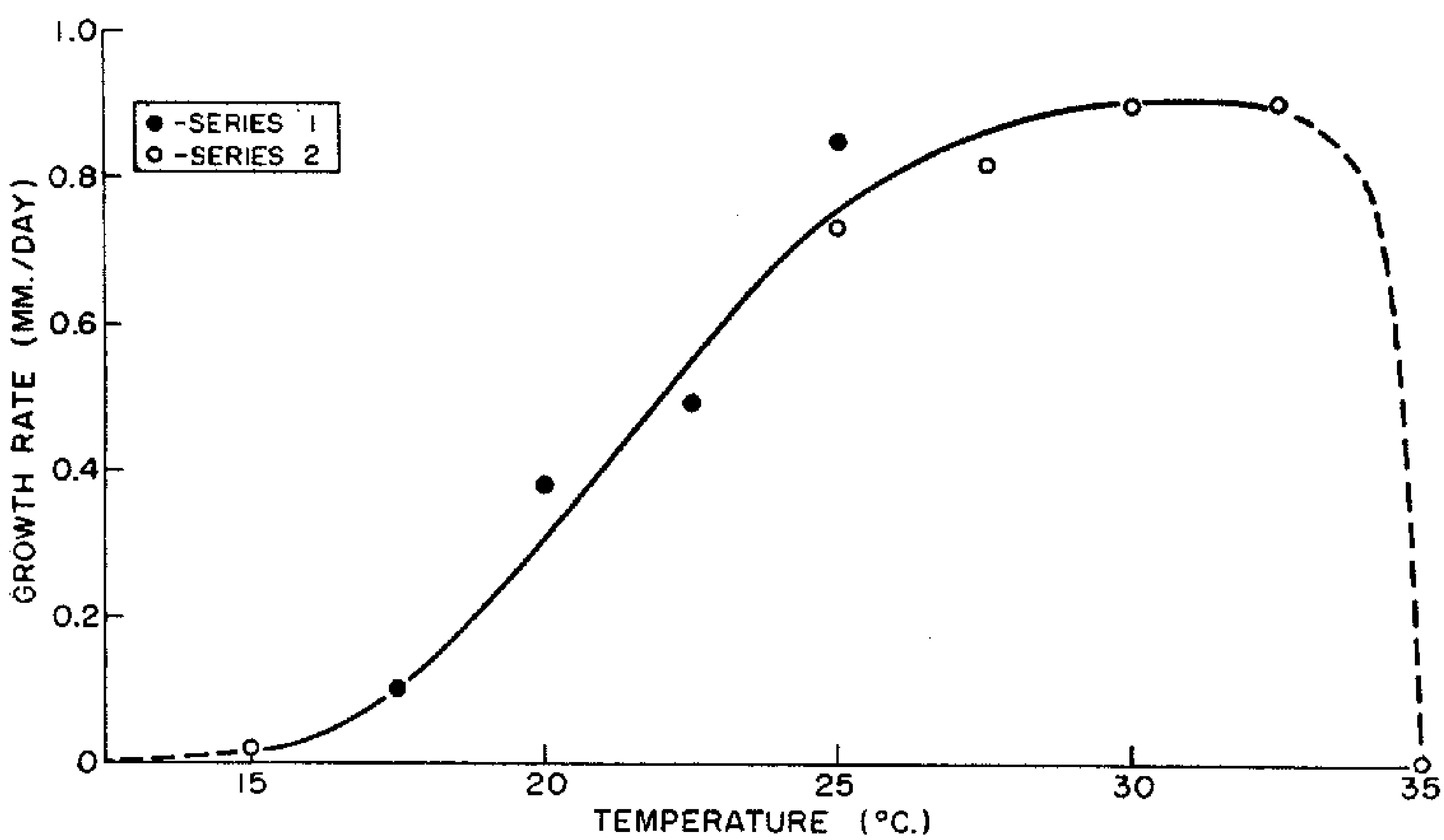

FIGURE 4. Growth rate (mm./day) of *P. aztecus* postlarvae held one month at different temperatures. Rate determined by inspection from straight-line portions of curves in Figure 2.

period (about 5-day intervals), two postlarvae were taken from each aquarium. The 10 animals from a given temperature constituted a sample. Postlarvae were weighed and measured individually as described by Zein-Eldin (1963). At the completion of the study, all remaining shrimp were weighed and measured individually to check the reliability of the sampling procedure (Table I) and to determine the percentage survival at each temperature.

Results

Growth

The final mean size of the postlarvae, whether derived from length or weight (Figs. 1 and 2, and Table I), increased with temperature between 15° and 32.5° C. Growth rate, however, decreased markedly at 35° C., an effect evident in the samples taken on the 11th day. The greatest difference in growth between adjacent temperatures occurred between 17.5° and 20° C. and between 22.5° and 25° C. (Fig. 3). As a result, the increase in growth rate per unit of temperature was greatest in the temperature range 17.5° to 25° C. This differential effect of temperature is illustrated in Figure 4, an S-shaped curve with a maximum (at 30°

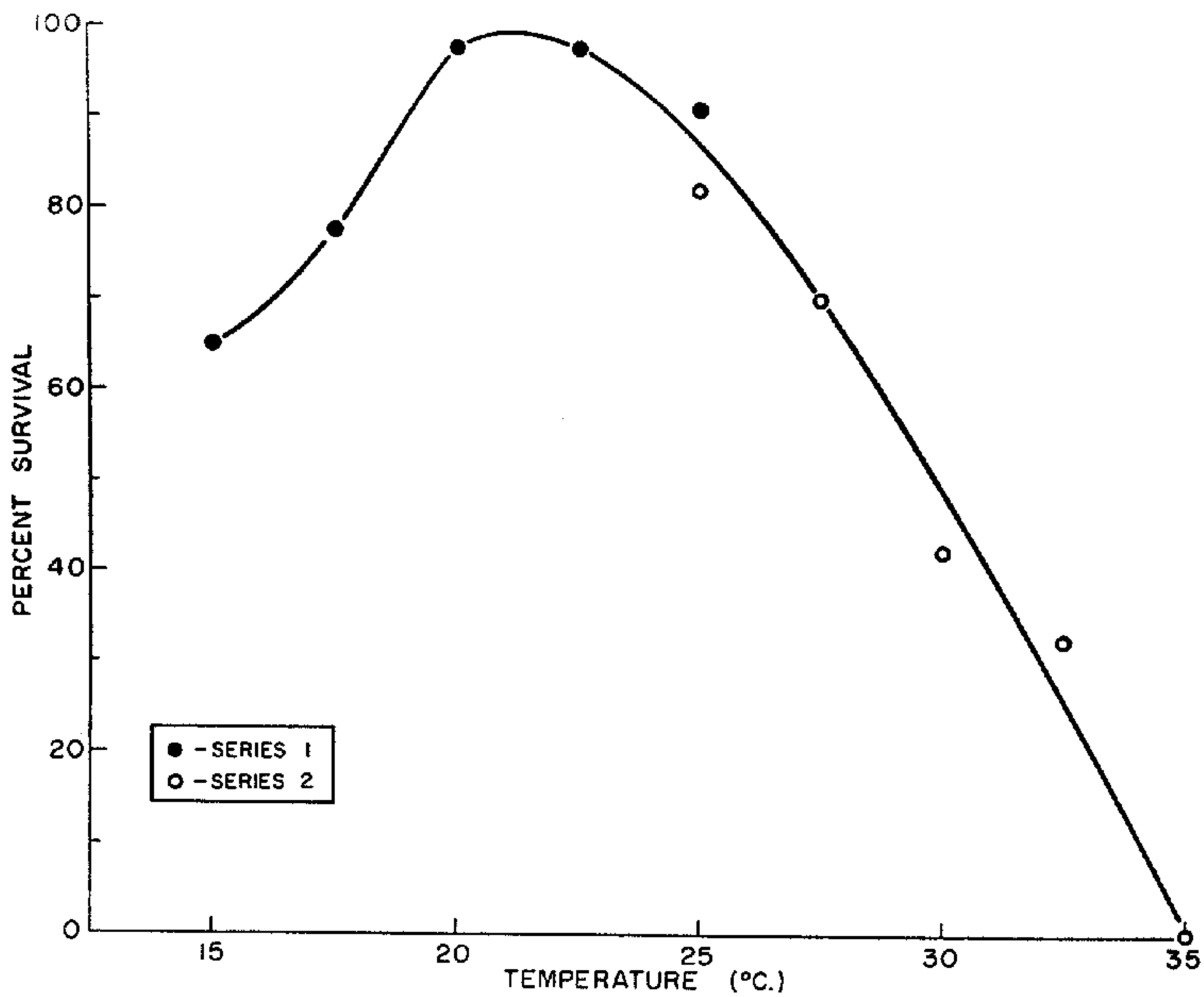

FIGURE 5. Per cent survival of *P. aztecus* postlarvae held at different temperatures for one month.

to 32.5° C.) typical of invertebrate growth responses to temperature (Needham, 1964, p. 416). In Series 2, final size did not differ significantly between groups exposed to temperatures of 27.5° to 32.5° C. (Fig. 3).

Survival

The relation of survival to temperature was somewhat different. The percentage survival increased with temperature between 15° and 20° C., remained above 90% at 22.5° and 25° C., but dropped at temperatures above 25° C. (Fig. 5). At 35° C., no animals remained after the 15th day. A similar decrease in survival at 32° C. as compared with 25° C. was noted in earlier experiments in our laboratory (Table II).

Gross production

Gross production, as estimated by comparing the total weight gains of the postlarvae surviving exposure to each temperature, was used to assess the combined

TABLE II

Comparison of growth of P. aztecus postlarvae from various experiments

Experiment no.	Date	Volume of experimental unit (liters)	No. of animals per experimental unit	Illumination*	Temperature (°C.)	Mean increase in length (mm.)	Duration of experiment (days)	Mean growth rate (mm./day)	Δ^t/Δ^{25}**	Survival (%)
GS-1†	4/62	45	100	+	24.0	19.0	28	0.68	1.00	36
GS-2†	8/62	45	100	+	26.0	17.4	29	0.60	1.00	100
GTS-1††	3–4/63	45	100	+	25.0	22.3	28	0.80	1.00	100
GT-F1	4/64	45	100	+	25.0	25.2	30	0.84	1.00	100
Series 1#	4/64	4	20	–	25.0	21.0	31	0.68	1.00	91
GTS-3	8/64	45	90	+	25.0	20.3	28	0.72	1.00	100
Series 2##	8/64	4	20	–	25.0	17.0	29	0.59	1.00	82
GTS-1††	3–4/63	45	100	+	32.0	32.0	28	1.14	1.38	58
GTS-2	8/63	45	40	+	32.0	30.4	29	1.05	—	34
GTS-3	8/64	45	90	+	32.0	27.2	28	0.97	1.35	100
Series 2##	8/64	4	20	–	32.5	24.6	29	0.85	1.46	32
GTS-1††	3–4/63	45	100	+	18.0	7.4	28	0.26	0.32	100
GTS-2	8/63	45	40	+	18.0	5.2	29	0.18	—	95
GT-F1	4/64	45	100	+	18.0	5.9	30	0.20	0.24	100
Series 1#	4/64	4	20	–	17.5	2.5	31	0.08	0.12	78
GTS-3	8/64	45	90	+	18.0	2.0	28	0.07	0.10	100
GTS-1††	3–4/63	45	100	+	11.0	0.5	28	0.02	0.025	92
GT-F1	4/64	45	100	+	11.0	0.0	30	0.00	0.00	26
GTS-3	8/64	45	90	+	11.0	1.1	28	0.04	0.05	5

* + indicates continuous fluorescent illumination; – continuous darkness.
** Δ^t = mean growth rate at temperature t; Δ^{25} = mean growth rate at 25°.
† Data from Zein-Eldin, 1963.
†† Data from Zein-Eldin and Aldrich, 1965.
\# Animals from same population as those in GT-F1.
\## Animals from same population as those in GTS-3.

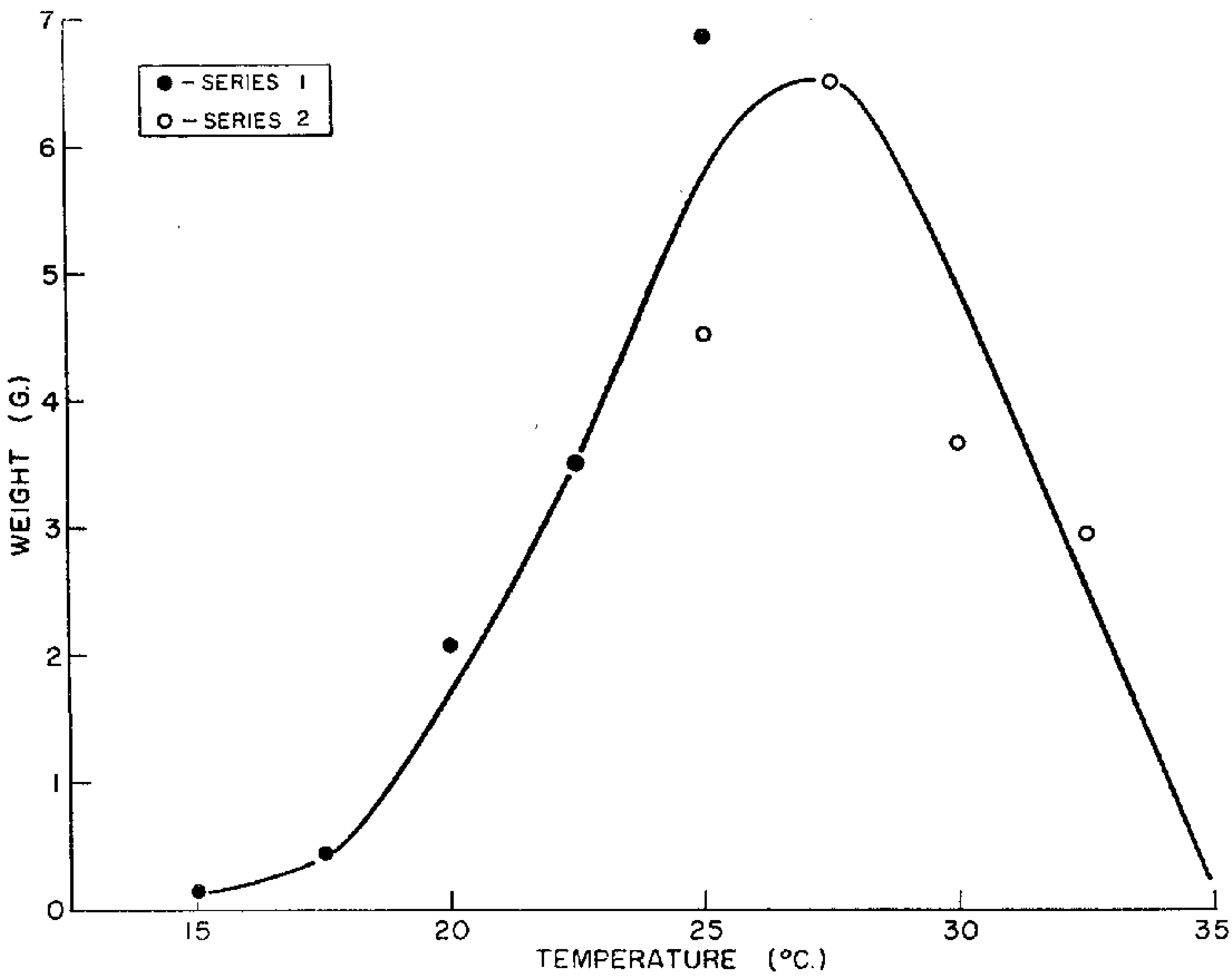

FIGURE 6. Increase in total weight of postlarval *P. aztecus* surviving different temperatures for one month.

effects of growth and mortality (Fig. 6). The total weight gain was maximal at temperatures of 25° and 27.5° C.; under laboratory conditions, the increased mortality at higher temperatures apparently has a greater effect on production than has the accelerated growth of survivors.

Food conversion

The efficiency of food conversion in these experiments was 10% to 15% lower than that determined in previous work in which large tanks and continuous light were used (Zein-Eldin and Aldrich, 1965). Efficiencies were approximately 30% at all temperatures except 15°, 17.5°, and 35° C. The efficiency declined to 15% at 17.5° C. and to 9% at 15° C.

Temperature relations

Growth rates at 25° C. were greater in Series 1 than in Series 2 (Figs. 1 and 2). The previous temperature history of the animals in the two series did not appear to explain the differences in either growth rate or survival. If past temperature history were a major factor in determining growth rate and survival, animals obtained in August would be expected to grow faster and survive better at high temperatures (30° C. and greater) than those obtained in April when temperatures were considerably lower. Conversely, spring animals might be expected to grow and survive somewhat better at temperatures below 20° C. than animals obtained at higher August temperatures. To compare various wild populations exposed to the same conditions, we examined the growth data from several experiments (identified only by code numbers in Table II) performed in our laboratory during the past few years. Spring postlarvae did grow slightly more rapidly at 18° C., but animals collected in August neither grew more rapidly nor survived better at 32° to 32.5° C. than those collected in the spring (Table II).

To obtain further information concerning the effects of temperature on a given population, the mean increase in length of animals held at 25° C. in a given experiment was chosen as a standard, and the growth at other temperatures was compared with that at 25° C. (mean growth at temperature T divided by mean growth at 25° C.; Table II). The ratio of growth to that of the standard was nearly constant at 11° or 32° C., but was variable between 17.5° and 18° C. The variability at 17.5° to 18° C. may arise from the relatively great effect of temperature on the growth rate at this temperature range.

The somewhat reduced growth rates in these series were apparently caused by crowding. Higher growth rates were attained by animals from the same postlarval populations when reared in larger illuminated tanks (Experiments GT-F1 and GTS-3 of Table II). If the growth rates of animals from Experiment GT-F1 are compared with those of Series 1, or rates from GTS-3 with those of Series 2, rates in the two series are 0.8 of those in the larger tanks and, thus, correspondingly larger volumes of water. This reduced growth may have been the result of the smaller water volume per animal (crowding) rather than the lack of light, since subsequent experiments have indicated that effects of light are negligible.

It seems apparent that in laboratory studies, actual growth rates of the animals depend upon the particular natural population of postlarvae used. Comparisons of the relative effects of temperature are, however, valid within a given group of animals.

Ecological Implications

A relation between temperature and growth rate of *P. aztecus* has also been suggested in reports on field studies by St. Amant, Corkum and Broom (1963), and Ringo (1965), who noted an apparent spurt of growth when the water temperature exceeds 20° C. Our results indicate that this pattern is a direct effect of temperature on the growth rate. The laboratory studies reported here also confirm the suggestion of Zein-Eldin and Aldrich (1965) that the influence of temperature on growth of postlarval brown shrimp is most marked in the 18° to 25° C. range.

Within the range of 15° to 20° C., small differences in temperature have a pronounced effect on the time needed for the completion of postlarval development in the laboratory (Fig. 7). The calculated time required for an average laboratory-held postlarva to increase from 12 to 25 mm. decreases from 260 days at 15° to 108 days at 17.5°, and to 36 days at 20° C. Temperatures greater than 20° C. bring about relatively minor decreases in the time required to complete postlarval development. That more rapid growth may occur in nature, where fluctuations

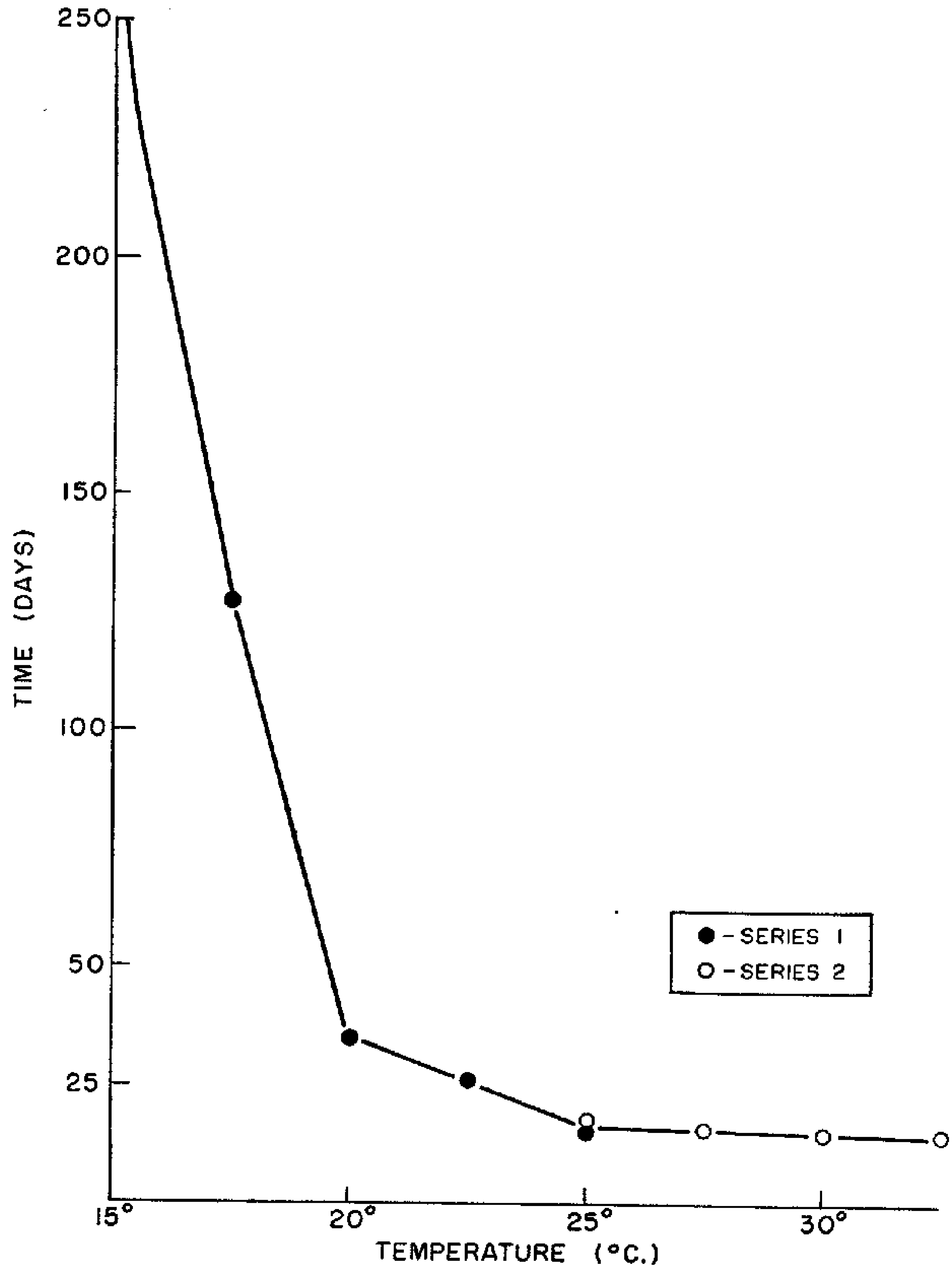

FIGURE 7. Number of days required for a 12-mm. postlarva of *P. aztecus* to grow to 25 mm. at different temperatures (based on slopes in Figure 4).

in temperature are the rule, must be re-emphasized. It is probable, however, that the growth rate below 20° C. is too slow to be readily observable in successive field samples.

Further observations are required to determine the degree to which other natural factors, such as food and light, influence the growth of postlarval *P. aztecus,* as well as that of *P. setiferus.*

SUMMARY

1. The growth of postlarval brown shrimp, *Penaeus aztecus,* was studied in the laboratory at constant temperatures of 15° through 35° C.

2. Growth increased with temperature up to 32.5° C. Maximal increases of growth rate per unit of temperature were observed in the temperature range of 17.5° to 25° C.

3. Survival for one month was markedly decreased at 32.5° C., and no animals survived at 35°.

4. The results suggest that in the laboratory gross production is optimal at temperatures of 22.5° to 30° C.

5. Non-lethal temperatures can have a strong effect on the time required to complete postlarval development.

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